Processing of GNSS and SLR observations from GNSS, SLR and LEO satellites in the Bernese GNSS Software

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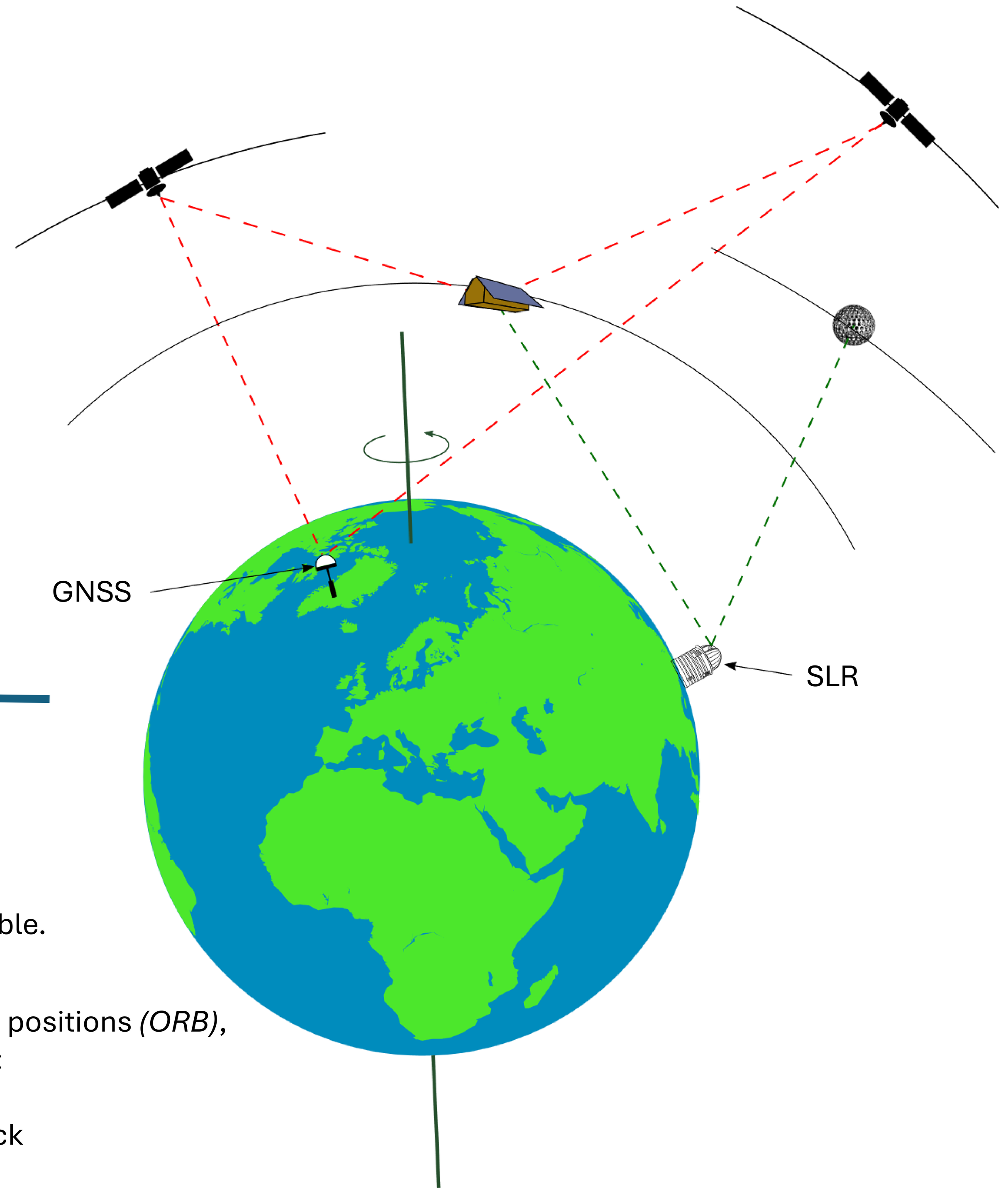
Context

The Bernese GNSS Software (BSW; Dach et al., 2015) is a high performance, high accuracy post-processing software package primarily used in the space-geodetic community for the analysis of GNSS and SLR data. It is:

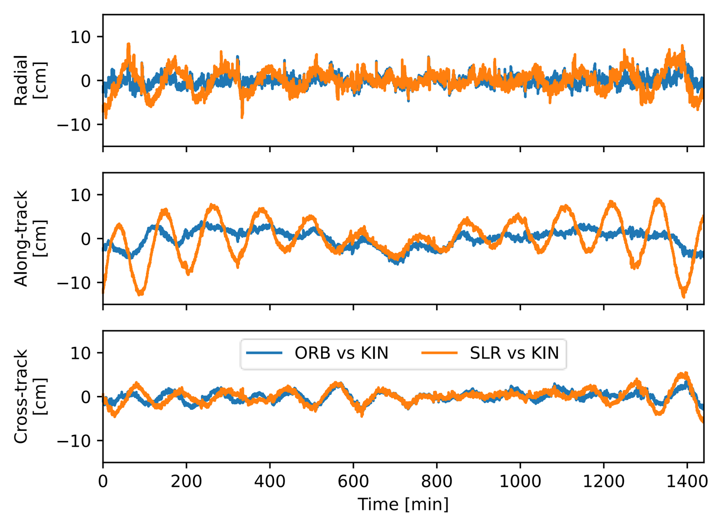
- Supported, maintained, and regularly updated by the Astronomical Institute of the University of Bern (AIUB),
- Consisting of 100+ programs and 1300 modules and subroutines,
- Used by more than 800 customers worldwide,
- Used to process GNSS data from ground station networks up to LEOs
- Used to process SLR data to geodetic and other satellites.
- Currently being extended to process VLBI observations.

In view of ESA's mission Genesis we present the capability of the BSW to process GNSS and SLR observations from GNSS and SLR spherical satellites and LEO satellites such as **Sentinel-6A** for the determination of:

- Station coordinates,
- Earth orientation parameters (EOP),
- Geocenter coordinates (GCC),
- Satellite orbits (SLR spherical satellites, LEO satellites, GNSS satellites)



SLR-based orbit determination of Sentinel-6A



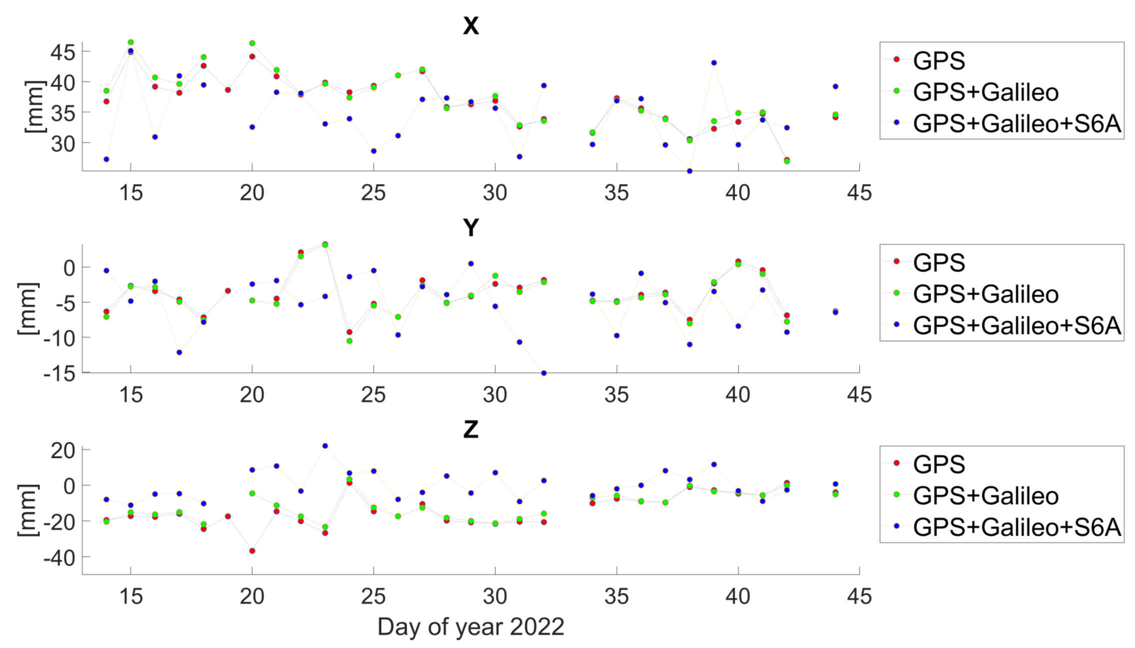
- SLR processing for LEO satellites was limited to SLR validation.
- SLR-based parameter estimation using attitude data is now possible.

- We fitted a Sentinel-6A orbit using either GNSS-derived kinematic positions *(ORB)*, or only SLR observations *(SLR)* with the following parametrization:
  - Constant acc. in radial, along-track and cross-track
  - Once-per-revolution acc. in Radial, Along-track and Cross-track

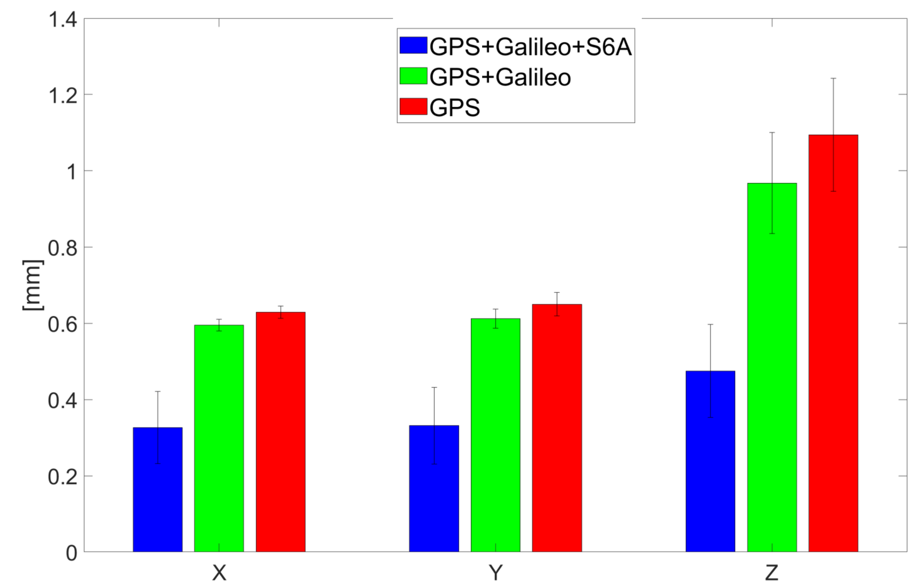
- Considering the the number of available SLR observations, SLR-derived orbit shows a good agreement with the GNSS-derived orbit, when compared to GNSS-derived kinematic positions *(KIN)*.
- Proper SLR observations screening may improve the orbit fit.

Global multi-GNSS network solution including Sentinel-6A GNSS observations

- GNSS observations to Sentinel-6A and GNSS ground stations are jointly processed estimating GNSS and LEO orbit parameters, Earth Orientation Parameters, **geocenter corrections** and station coordinates.
- LEO orbit parameters are pre-eliminated before writing a combined normal equation system, then back-substituted (Kobel, 2024).



Estimated geocenter coordinates (Kobel, 2024)



Mean values and standard deviation of formal errors of daily estimates of geocenter coordinates (Kobel, 2024)

- mm-level differences between the GPS-only and GPS+Galileo solutions based on GNSS ground station data.
- Adding GNSS observations from Sentinel-6A leads to notably different estimates, with **lower formal errors**.
- An offset in the estimated Z-component between the LEO integrated solution and the two GNSS-only solutions.
  → GPS-only solution is heavily affected by modeling errors of the GPS orbits (Meindl et al., 2013).

Comparison with estimates from an SLR solution (Geisser, 2023)

- Significant **reduction of the mean value** of the differences for the LEO-integrated solution
- Larger standard deviation for the LEO-integrated solution (long-arc approach may stabilize the solution)

	[mm]
GPS	-17.0±5.7
GPS+Galileo	-15.4±5.2
GPS+Galileo+S6A	-3.5±6.5

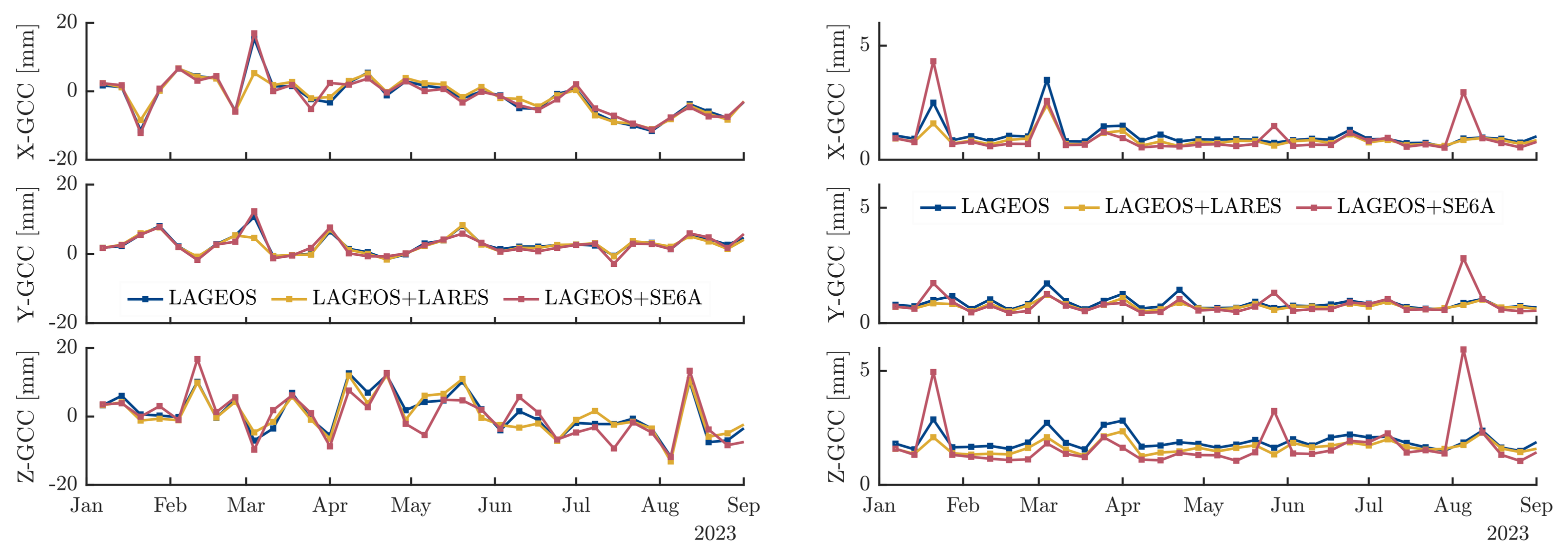
Earth's center-of-mass coordinates (Z) differences to an SLR solution (Kobel, 2024)

Global SLR network solution combining SLR spherical satellites and Sentinel-6A

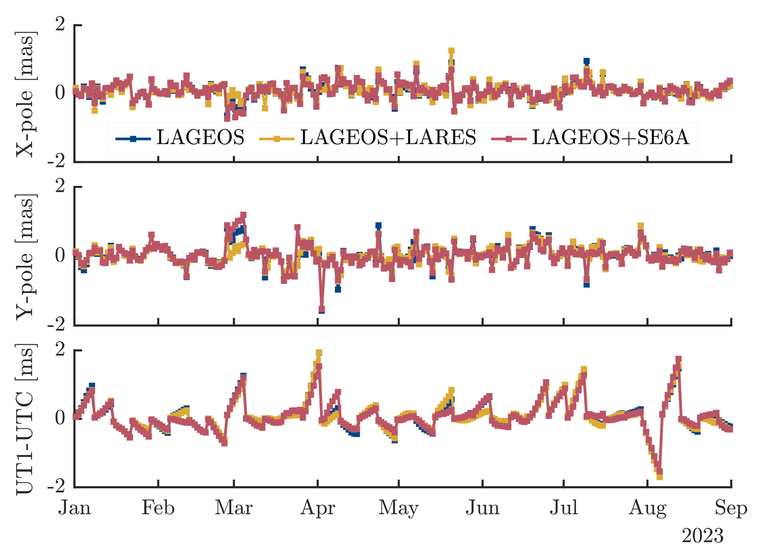
- Sentinel-6A parametrization identical to LARES
  - Constant acc. in Along-track
  - Once-per-revolution acc. in along-track and cross-track
  - 24 pulses/day in along-track

- Sentinel-6A (or LARES) alone do not provide reasonable estimation of EOP and GCC

In combination with LAGEOS-1/2, either LARES or Sentinel-6A **improve UT1-UTC**, and **reduce GCC formal errors**, without degrading the pole position.



Weekly estimated geocenter coordinates (left)and formal errors (right)



	X-pole [µas]	Y-pole [µas]	UT1-UTC [µs]
LAGEOS	158	157	93
LAGEOS +LARES	159	162	89
LAGEOS +SE6A	178	158	92

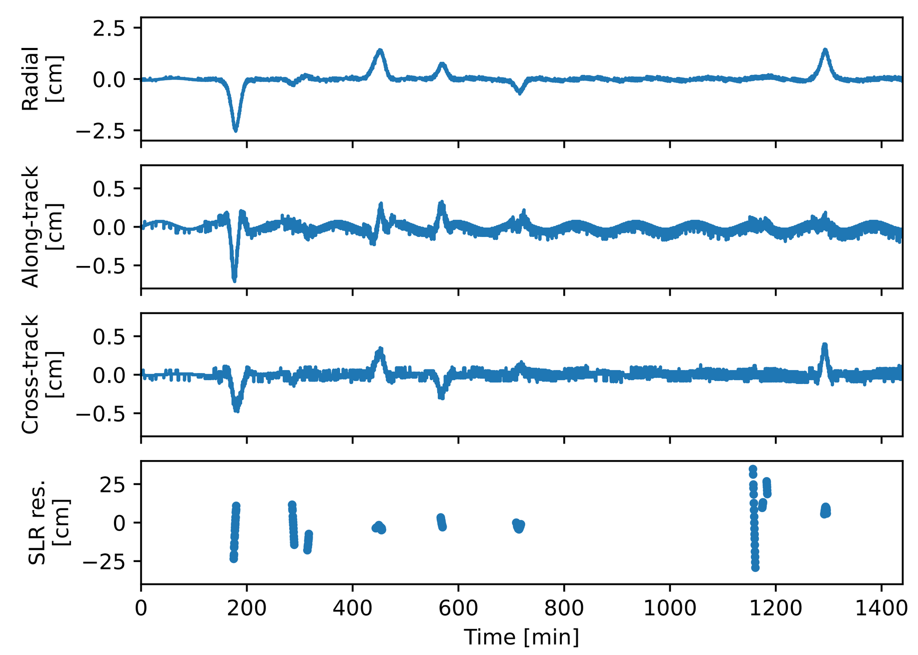
Difference between estimated ERPs and C04 weekly time series, and weighted RMS

SLR/GNSS-based orbit determination of Sentinel-6A

- Sentinel-6A parametrization:
  - 92 PCA in Radial, Along-track, Cross-track
  - Constant acc. in Along-track
  - Ambiguities pre-eliminated prior to combination

- When compared to kinematic positions, both orbits shows cm-level differences.

- Comparing the two orbit solutions shows:
  - Sub-mm level RMS differences
  - mm to cm level peaks, correlated with SLR passes
- Proper screening and/or estimating range biases could improve the solution



Orbit differences between GNSS-derived orbit and GNSS/SLR derived orbit, with corresponding SLR residuals

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References

Geisser (2023). *Generation and analysis of satellite laser ranging normal points for geodetic parameter estimation.* PhD thesis, Universität Bern.
Kobel (2024). *Incorporation of LEO GNSS observations into global network solutions*. PhD thesis, Universität Bern.
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Acknowledgement

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